Spatio-temporal Variability in Rainfall Across the SuDS+ Study Area Between January 2024 and June 2026: Implications for SuDS+ and Catchment Management

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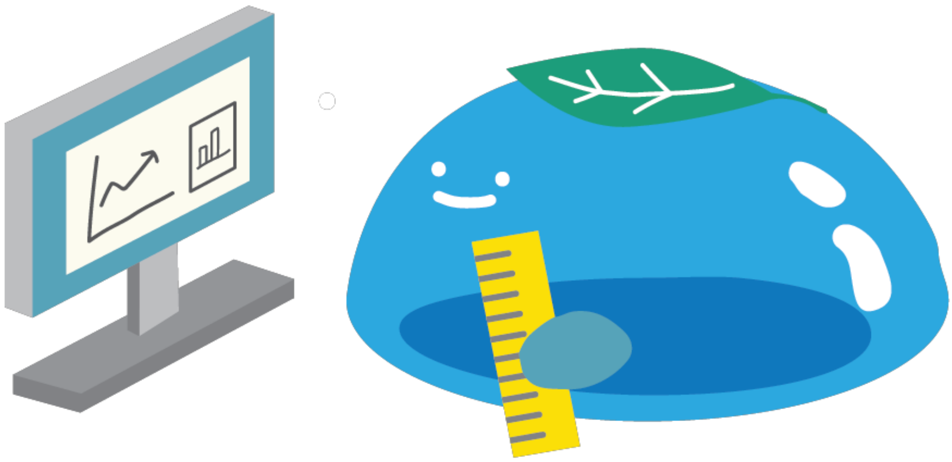

1. Introduction

Sustainable drainage systems (SuDS) are defined as a sequence of practices and technologies used to drain surface water/stormwater from a site through the replication of natural, pre-development drainage patterns (Fletcher et al. 2015). In UK practice, SuDS are increasingly implemented to reduce the speed and quantity of surface runoff whilst providing wider social and environmental benefits (CIRIA 2015). The evaluation of SuDS efficacy requires an assessment of local precipitation patterns driving hydrological response. In particular, analysis of variations in rainfall arising from storm characteristics, topography, and atmospheric conditions can support more informed catchment management (Berne and Krajewski 2013).

This report aims to characterise the spatio-temporal variability in rainfall within the Upper Twizell Burn catchment as part of the Stanley SuDS+ project, which operates within the study area depicted in Figure 1. Three principal research objectives were established to achieve this.

- **Objective One**: Delineate the catchment boundary, and determine the relative spatial weighting of each rainfall gauge within this area;
- **Objective Two**: Aggregate time-series precipitation data across annual, monthly, daily, and hourly scales to identify temporal patterns in precipitation volume and intensity; and
- **Objective Three**: Identify significant storms occurring within the monitoring period to assign estimated return periods using Flood Estimation Handbook (FEH) depth-duration-frequency (DDF) values.

2. Methodology

The data required to fulfil these objectives were obtained from the Stanley SuDS+ monitoring records and consisted of 2-minute resolution rainfall data recorded by three tipping-bucket gauges within the catchment area, starting in January 2024. FEH DDF values were also utilised for storm analysis. All data processing was undertaken in ArcGIS Pro 3.5 and Excel.

2.1 Objective 1

Considering the first research objective, the SuDS+ rainfall data were imported into a new geodatabase within ArcGIS Pro 3.5 and divided by gauge into three separate tables. The XY Table to Point tool was used to produce a spatial point for each gauge based on location, although these have been generalised in final figures.

Ordnance Survey (OS) Terrain 5m Digital Terrain Model (DTM) (OS 2026) data was added to the project to begin delineation of the catchment boundary. Relevant tiles covering the watershed area were merged to produce a new raster, which was subsequently filled to eliminate potential depressions in the terrain data. This allowed the Flow Direction and Flow Accumulation tools to be applied to the filled DTM. The point data representing Gauge 003 (G003), which is situated close to the catchment outlet, was exported to a new layer. As G003 does not sit directly atop a tributary, the Snap Pour Point tool was utilised with a distance of 100m to ensure that the watershed outflow was located on the nearest high flow cell. The Watershed tool was used to delineate the catchment boundary, and the resulting raster was converted into a polygon. Polygon area was determined using Calculate Geometry Attributes.

Thiessen polygons were produced using the rainfall gauge point data and were subsequently clipped to the watershed polygon. The area and weighting of each Thiessen polygon was calculated using Calculate Geometry Attributes.

2.2 Objective 2

Regarding the second research objective, the 2-minute resolution rainfall data were aggregated into 'Year', 'Year_Month', 'Day', and 'Hour' fields per rainfall gauge, and Summary Statistics were calculated for each timescale to determine the SUM, MEAN, MAX, and MIN rainfall.

The results of these calculations were exported into Excel alongside the Thiessen polygon weightings, facilitating the calculation of catchment-averaged monthly rainfall. In addition, cumulative rainfall totals were determined for each gauge across the monitoring period, as well as catchment-averaged cumulative rainfall. Daily rainfall SUM data were sorted by largest values to identify the 20 highest rainfall days recorded by each gauge during the monitoring period. Hourly rainfall SUM data were combined to calculate the catchment-averaged hourly rainfall; Object ID fields for each gauge were aligned to ensure that the data all began at the same hour for storm analysis.

2.3 Objective 3

To fulfil the third research objective, storms were identified using the catchment-averaged hourly rainfall time series, with storm events being registered when rainfall > 0mm following 6 ≤ consecutive dry hours. Each storm was given a start and finish hour and was sorted from largest to smallest according to catchment-averaged hourly rainfall SUM. The 10 storm events with the highest catchment-averaged hourly rainfall SUM were selected, and the relevant hourly rainfall SUM from each gauge was exported to determine the 'wettest' gauge during each storm. Maximum rolling rainfall depths were calculated at 1, 3, 6, 12, 24, 48, and 72 hours (where applicable) using the hourly rainfall time series from the wettest gauge for each of the 10 selected storms. These values were compared against published FEH DDF values to assign estimated return periods for each storm.

3. Results

Firstly, Figure 1 presents the generalised locations of each rain gauge within the catchment watershed, in addition to the spatial weighting of each gauge's Thiessen polygon. A graduated symbology has been applied to demonstrate the recorded cumulative rainfall of each gauge over the monitoring period. It is evident that Gauge 001 (G001) and Gauge 002 (G002) possess similar cumulative rainfall totals of 1853.57 mm and 1851.56 mm, whereas G003 holds a value of 1773.20 mm. These results yield a range of 80.37 mm in cumulative catchment-averaged rainfall, with a mean of 1837.12 mm. Additionally, the area of the watershed was found to be 13.17 km^2 which is approximately 4 % larger than the FEH estimate of 12.65 km^2.

Figure 2 depicts the monthly catchment-averaged rainfall throughout the monitoring period. This graph does not reveal a strongly discernible monthly trend, as fluctuations in rainfall totals appear to be irregular. However, no statistical analyses have been undertaken to confirm this pattern. The data indicates that the highest monthly value on a catchment-scale occurred in November 2025, whereas the lowest monthly value occurred in April 2025. Furthermore, Figure 3, which demonstrates monthly rainfall totals according to gauge, corroborates these findings by suggesting that November 2025 was the wettest month across all three gauges, and April 2024 was the driest.

Turning now to Figures 4a, 4b, and 4c, the 20 wettest days recorded by each gauge across the monitoring period are presented. Figures 4a and 4b show that the three wettest days documented by G001 and G002 were 20/09/2025, 26/09/2024, and 22/05/2024 respectively, whereas Figure 4c shows that the three wettest days documented by G003 were 26/09/2024, 20/09/2025, and 06/01/2025 respectively. The highest rainfall recorded by a single gauge within one day was 53.20 mm at G002 on 20/09/2025, as presented in Figure 4b.

Finally, Tables 1 and 2 depict the results of the storm analysis performed for the 10 largest storm events within the monitoring period. The Tables suggest that the largest storm by rainfall SUM occurred between 17:00 on the 25/09/2024 and the 27/09/2024, with an estimated return period of 10 – 20 years. This aligns with the wettest recorded days at all rain gauges, where the 26/09/2024 was either the highest or the second-highest daily rainfall SUM. The majority of the storm events selected for analysis (60%) have estimated return periods of either < 2 years, or between 2 and 5 years.

4. Discussion

These results provide a contextual grounding for the interpretation of SuDS+ hydrological monitoring across the Upper Twizell Burn catchment. Firstly, the spatial variations in cumulative rainfall data portrayed by Figure 1 imply that G001 and G002 have recorded higher rainfall totals throughout the monitoring period than G003. Hydrological variability is expected in small catchments such as the SuDS+ study area, where differential rainfall may result from topographic 'rain shadow' effects or changing atmospheric conditions (Cristiano et al. 2017). For example, G001 and G002, situated within the upper study area and urban part of the catchment respectively, could be experiencing higher rainfall totals due to orographic enhancement (Roe 2005) and urban heat island effects (Liu and Niyogi 2019). This variation in rainfall is particularly important to consider for projects such as Stanley SuDS+ where flows are likely to be highly sensitive due to fast hydrological response times at small catchment scales (Cristiano et al. 2017). Although, it should be noted that the areal weighting of rainfall calculated by Thiessen polygons may not be entirely representative of the catchment as it assumes hard boundaries in precipitation.

Considering temporal trends in rainfall, the results suggest that the highest totals were recorded in November 2025 at both an individual gauge scale and across catchment averages. This result is expected, as UK winter and autumn precipitation is expected to intensify in light of climate change moving forwards (Carruthers et al. 2026). Nevertheless, some totals presented within this report may seem superficially low as tipping bucket rain gauges struggle to accurately record forms of precipitation other than rainfall (e.g., snow, hail, sleet), (Savina et al. 2012). The observed maximum daily rainfall of 53.20mm on the 20/09/2025 represents a significant volume for the catchment, only 3.2mm lower than the highest-rainfall day recorded in County Durham since 2000 (Burt and Burt 2022).

Finally, the apparent largest storm recorded throughout the monitoring period had an estimated return period of 10 – 20 years, although 60% of analysed events had return periods of less than 5 years. This suggests that the dataset is dominated by relatively frequent events and is less representative of extreme storms. However, this is to be expected over a short monitoring period. It is important to note that the use of an alternative dry period duration during analysis may have resulted in different storm delineation and associated return period estimates.

5. Conclusion

Ultimately, this report has examined variability in rainfall duration and intensity across the Upper Twizell Burn catchment area managed by Stanley SuDS+, with conclusions presenting implications for the project. The temporal characterisation of rainfall may assist further hydrological data interpretation whilst allowing infrastructure performance to be assessed alongside periods of potentially high flow. Additionally, spatial representations of catchment rainfall could support flood-risk management and maintenance planning. Future studies could continue this analysis over an extended monitoring period, incorporating statistical testing as well as examining a larger number of storm events to strengthen the conclusions made.

6. Appendix of Figures

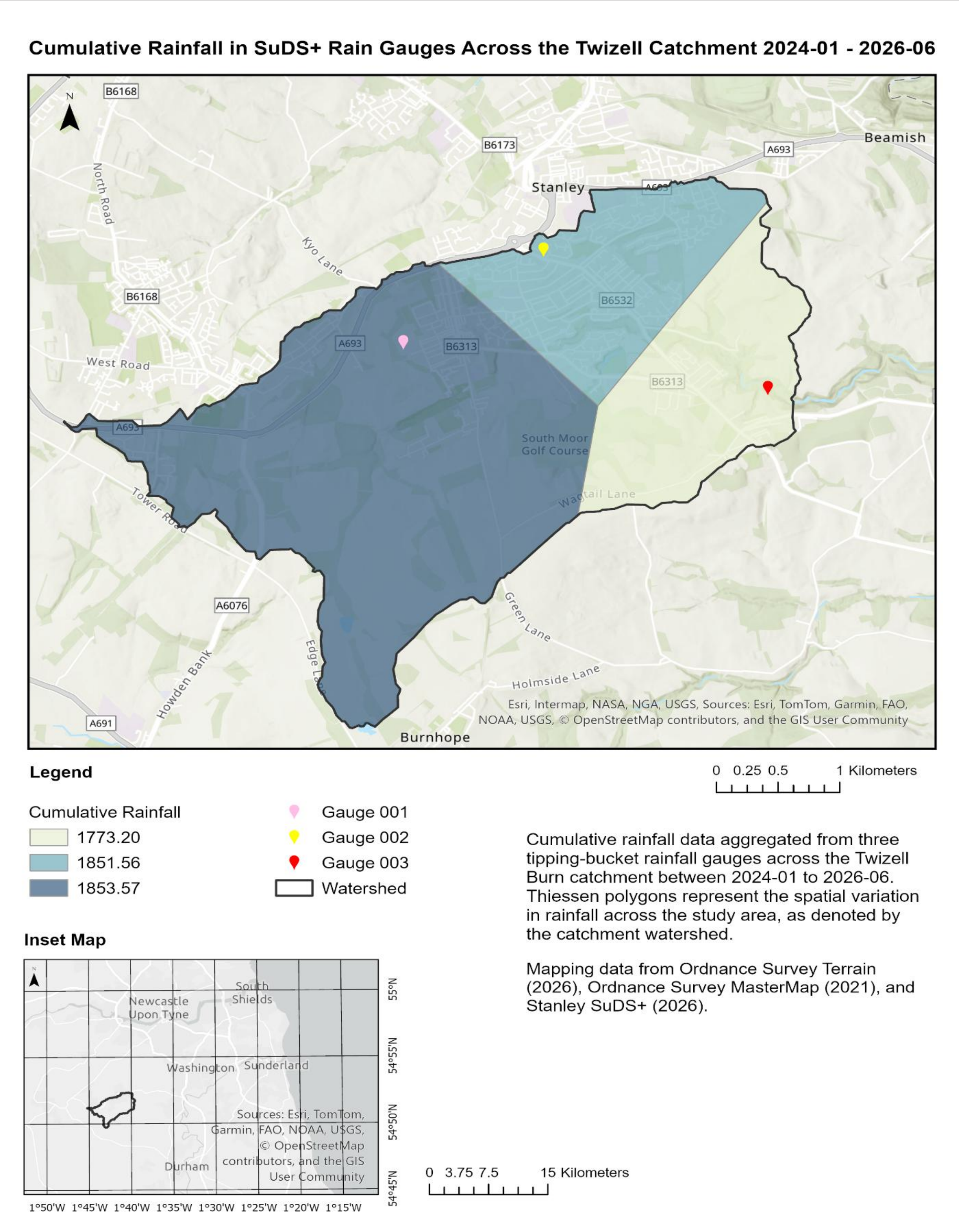

Figure 1: Cumulative rainfall (mm) recorded by SuDS+ rain gauges between 2024-01 – 2026-06 within the study area (Upper Twizell Burn catchment)

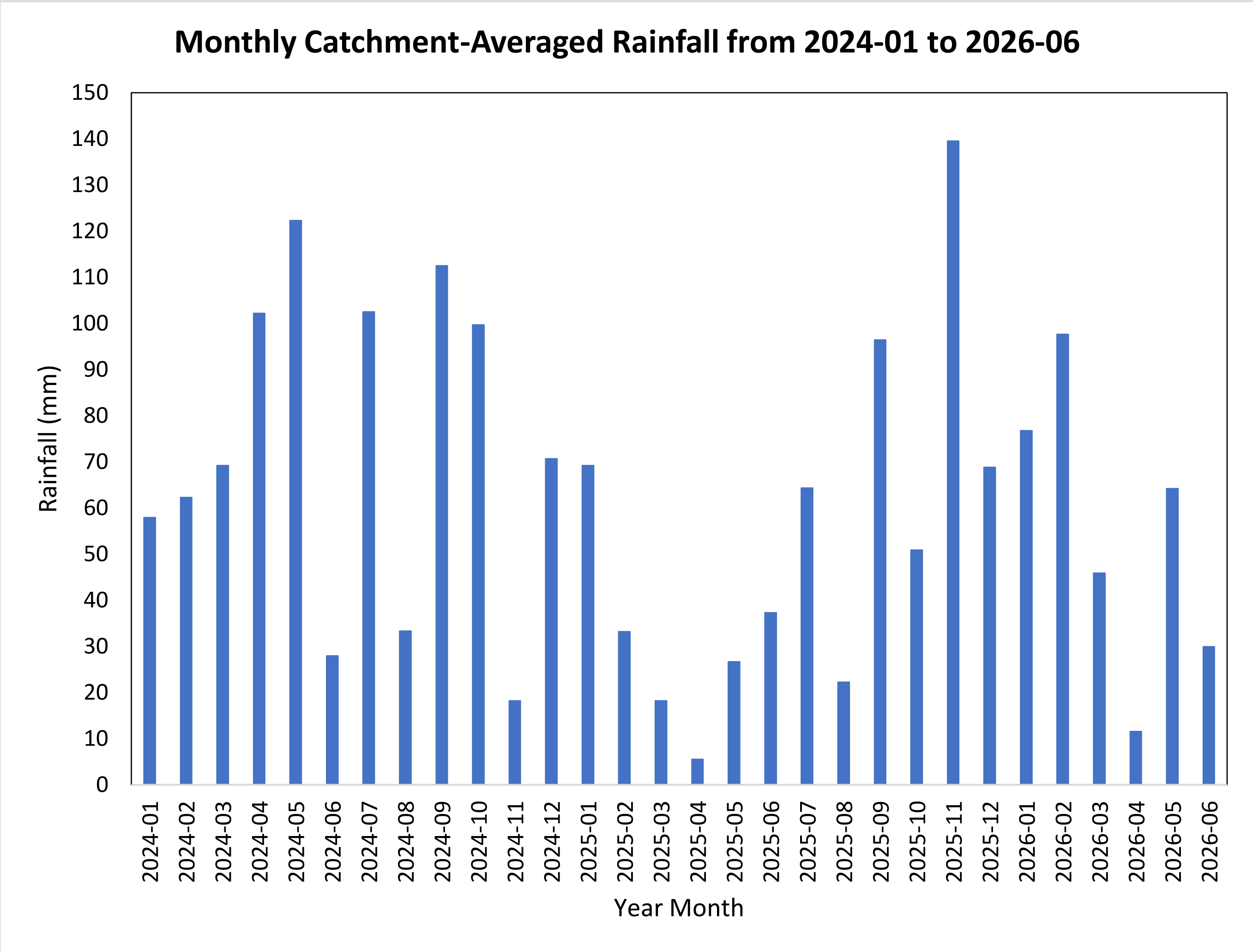

Figure 2: Monthly catchment-averaged rainfall (mm) from 2024-01 to 2026-06

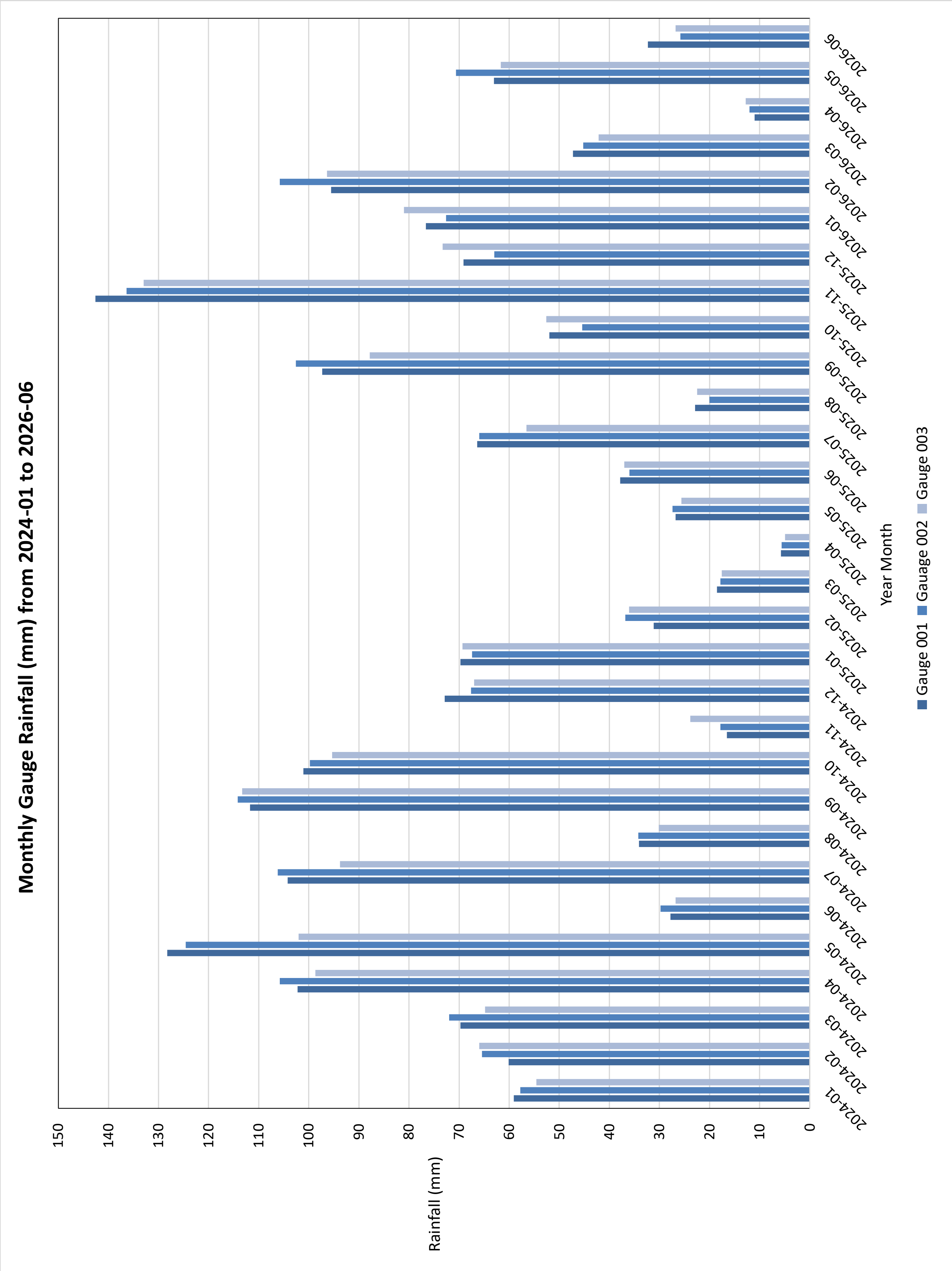

Figure 3: Monthly gauge rainfall (mm) from 2024-01 to 2026-06

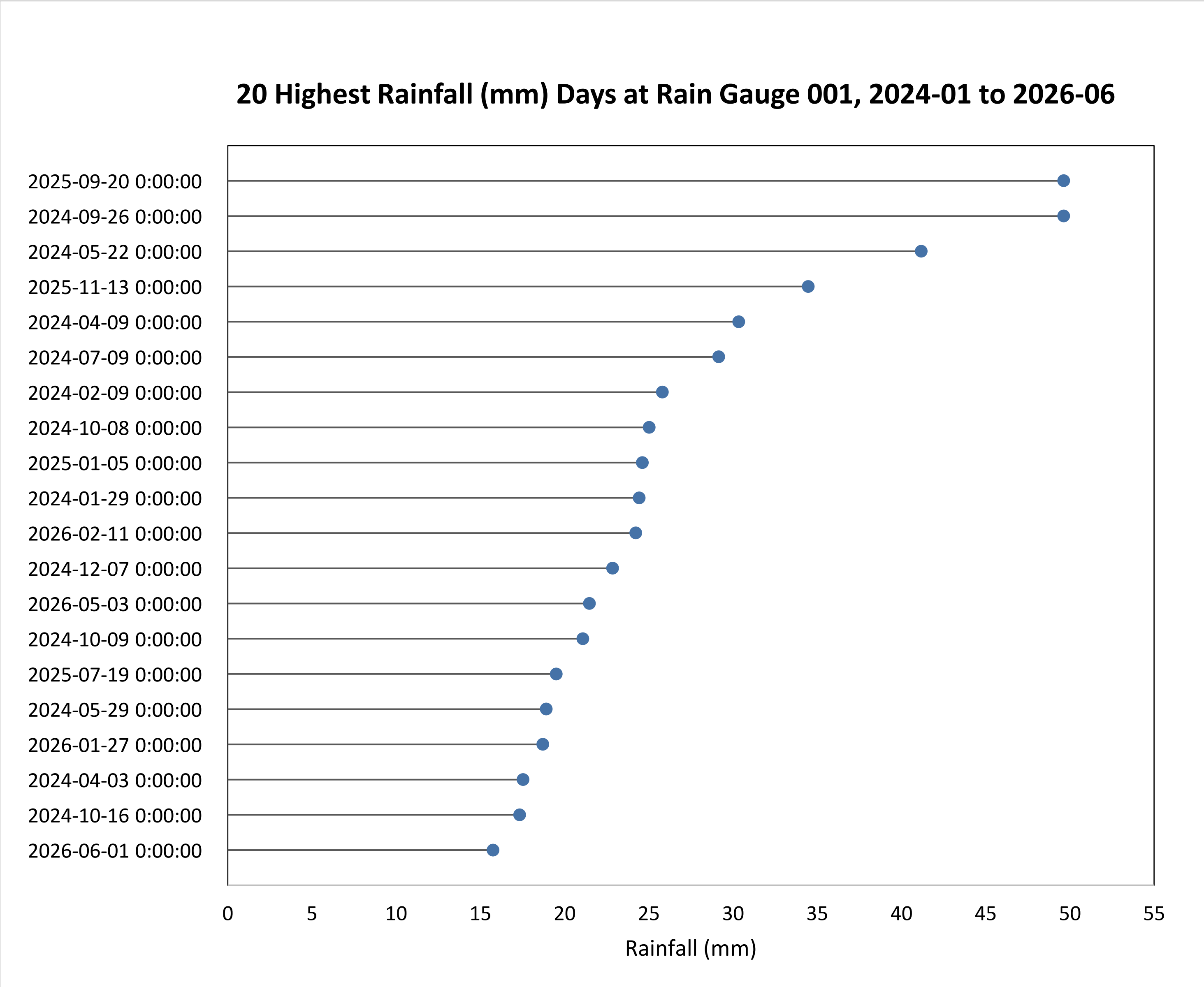

Figure 4a: The 20 highest rainfall (mm) days recorded at G001 from 2024-01 to 2026-06

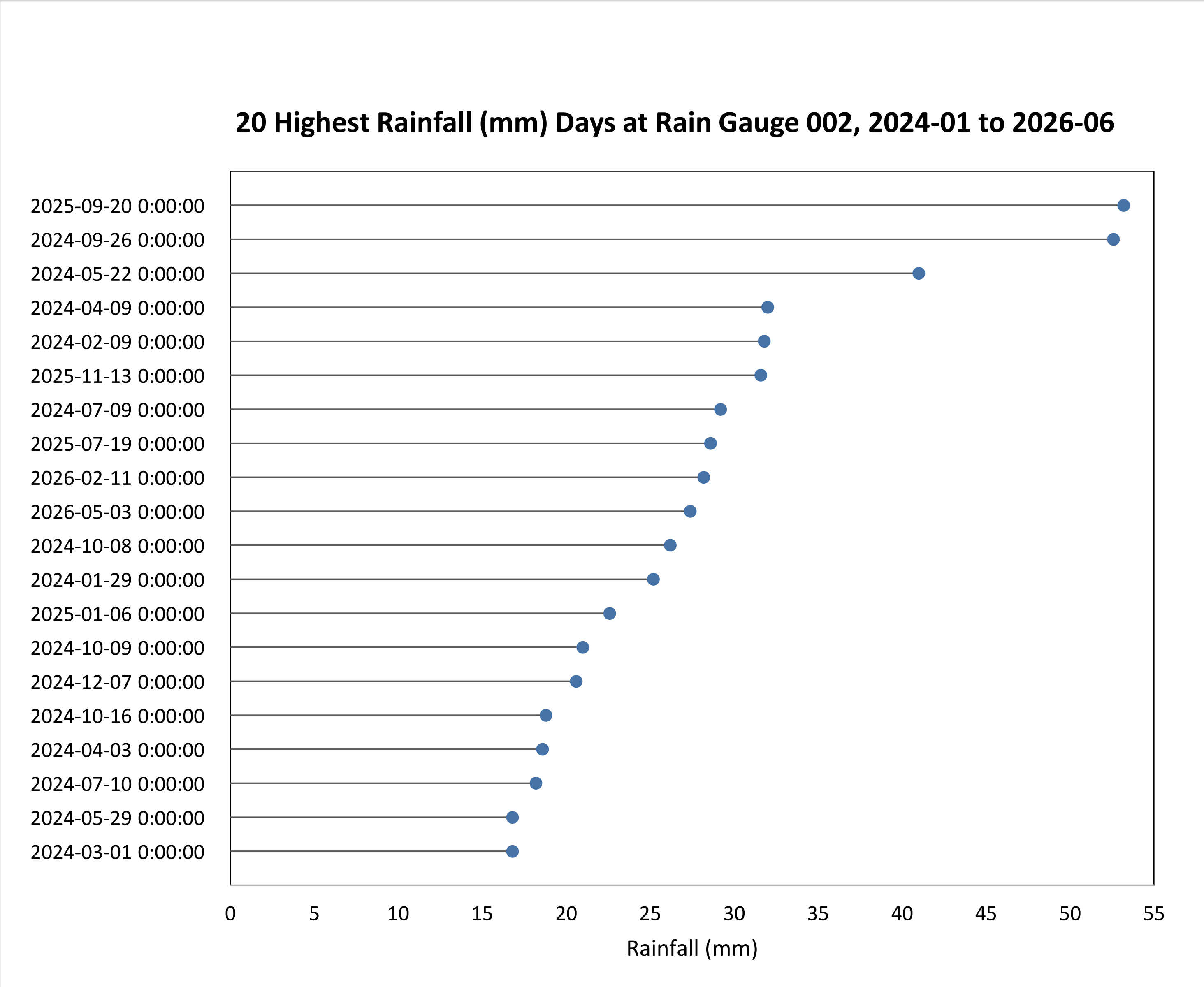

Figure 4b: The 20 highest rainfall (mm) days recorded at G002 from 2024-01 to 2026-06

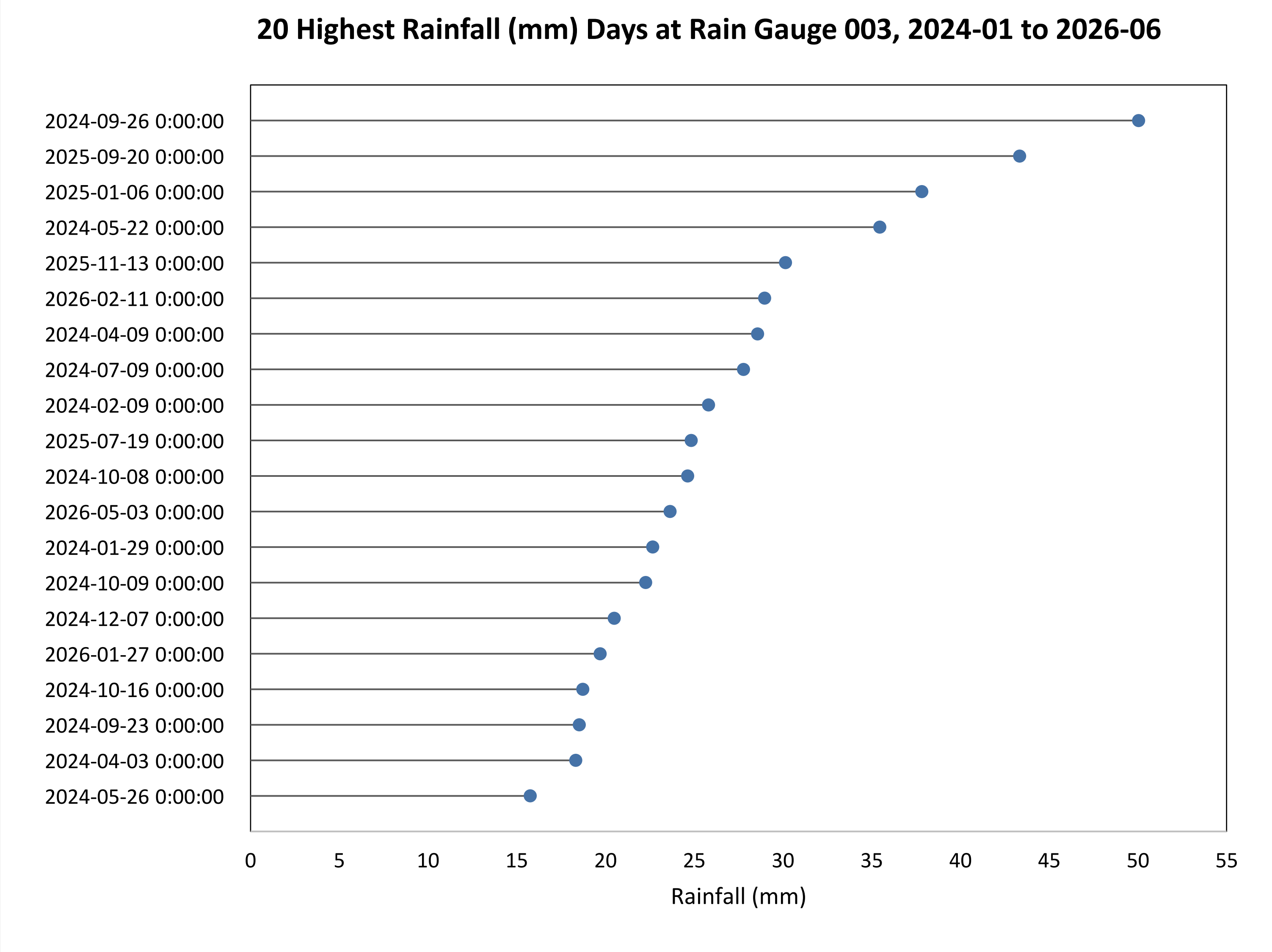

Figure 4c: The 20 highest rainfall (mm) days recorded at G003 from 2024-01 to 2026-06

Table 1: Maximum rolling rainfall depths (mm) for the 10 largest storms identified within the monitoring period (2024-01 – 2026-06), as ordered from largest to smallest based on rainfall totals

Storm ID	Storm Start	Storm End	Max Gauge	Max 1hr (mm)	Max 3 hr (mm)	Max 6 hr (mm)	Max 12 hr (mm)	Max 24 hr (mm)	Max 48 hr (mm)	Max 72 hr (mm)
184	25/09/2024 17:00	27/09/2024 07:00	G002	7	15.4	24.4	46	64.6		
417	12/11/2025 18:00	15/11/2025 11:00	G001	5.319	11.426	16.745	32.111	39.597	50.432	
380	19/09/2025 20:00	21/09/2025 01:00	G002	6.6	14.8	24.8	43	53.2		
92	22/05/2024 02:00	24/05/2024 06:00	G002	7	17	23.8	38.2	48		
488	10/02/2026 05:00	13/02/2026 18:00	G002	2	5.2	10.2	18.6	30.8	46.2	55
190	08/10/2024 00:00	10/10/2024 04:00	G002	8	9.2	12.4	16.2	28.4	47.2	
129	09/07/2024 06:00	10/07/2024 20:00	G002	6.2	13.4	21.8	28	36.4		
238	05/01/2025 13:00	06/01/2025 20:00	G001	3.349	10.047	16.154	26.398	38.809		
221	06/12/2024 18:00	09/12/2024 01:00	G001	2.955	6.895	10.835	18.321	27.383	38.612	
16	08/02/2024 11:00	10/02/2024 03:00	G002	2.6	6.8	10.6	21	36		

Table 2: Estimated FEH DDF return periods for the 10 largest storms identified within the monitoring period (2024-01 – 2026-06), as ordered from largest to smallest based on rainfall totals

Storm ID	Storm Start	Storm End	Max Gauge	1 hr	3 hr	6 hr	12 hr	24 hr	48 hr	72 hr
184	25/09/2024 17:00	27/09/2024 07:00	G002	< 2 yr	< 2 yr	2 - 5 yr	10 - 20 yr	10 - 20 yr		
417	12/11/2025 18:00	15/11/2025 11:00	G001	< 2 yr	< 2 yr	< 2 yr	2 - 5 yr	2 - 5 yr	5 - 10 yr	
380	19/09/2025 20:00	21/09/2025 01:00	G002	< 2 yr	< 2 yr	2 - 5 yr	10 - 20 yr	5 - 10 yr		
92	22/05/2024 02:00	24/05/2024 06:00	G002	< 2 yr	< 2 yr	2 - 5 yr	2 - 5 yr	5 - 10 yr		
488	10/02/2026 05:00	13/02/2026 18:00	G002	< 2 yr	< 2 yr	< 2 yr	< 2 yr	< 2 yr	< 2 yr	2 - 5 yr
190	08/10/2024 00:00	10/10/2024 04:00	G002	< 2 yr	< 2 yr	< 2 yr	< 2 yr	< 2 yr	2 - 5 yr	
129	09/07/2024 06:00	10/07/2024 20:00	G002	< 2 yr	< 2 yr	< 2 yr	< 2 yr	< 2 yr		
238	05/01/2025 13:00	06/01/2025 20:00	G001	< 2 yr	< 2 yr	< 2 yr	< 2 yr	2 - 5 yr		
221	06/12/2024 18:00	09/12/2024 01:00	G001	< 2 yr	< 2 yr	< 2 yr	< 2 yr	< 2 yr	< 2 yr	
16	08/02/2024 11:00	10/02/2024 03:00	G002	< 2 yr	< 2 yr	< 2 yr	< 2 yr	< 2 yr		

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